

Physics 129A

Introduction to Particle Physics

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3 Evans Tu -Th 11:00AM-12:30 PM

Disc. 41 Evans Tu 2:00PM-3:00 PM

Office Hours:

TBA

Today 2:00-4:00 PM

Short Discussion Section today to get acquainted.

Draft Syllabus:

- Overview of the history of Particle Physics
- Review of Relativity and Quantum Mechanics
- Introduction to Nuclear Physics
- Symmetries in Nuclear and Particle Physics and the Quark Model
- Relativistic Quantum Mechanics
- Feynman Diagrams
- QED
- QCD
- Weak Interactions
- Gauge Theories and the Standard Model
- Modern Topics: neutrinos, particle astrophysics,...

Suggested Texts:

Introduction to Elementary Particles -- David Griffiths

Introduction to High Energy Physics -- Donald H. Perkins

Quarks & Leptons: An Introductory Course in Modern Particle Physics -- Francis Halzen and Alan D. Martin

A longer list of textbooks will be provided.

Reading assignments from the texts and journals will be suggested.

Read Chapter 1 from Griffiths for this week.

Course Work

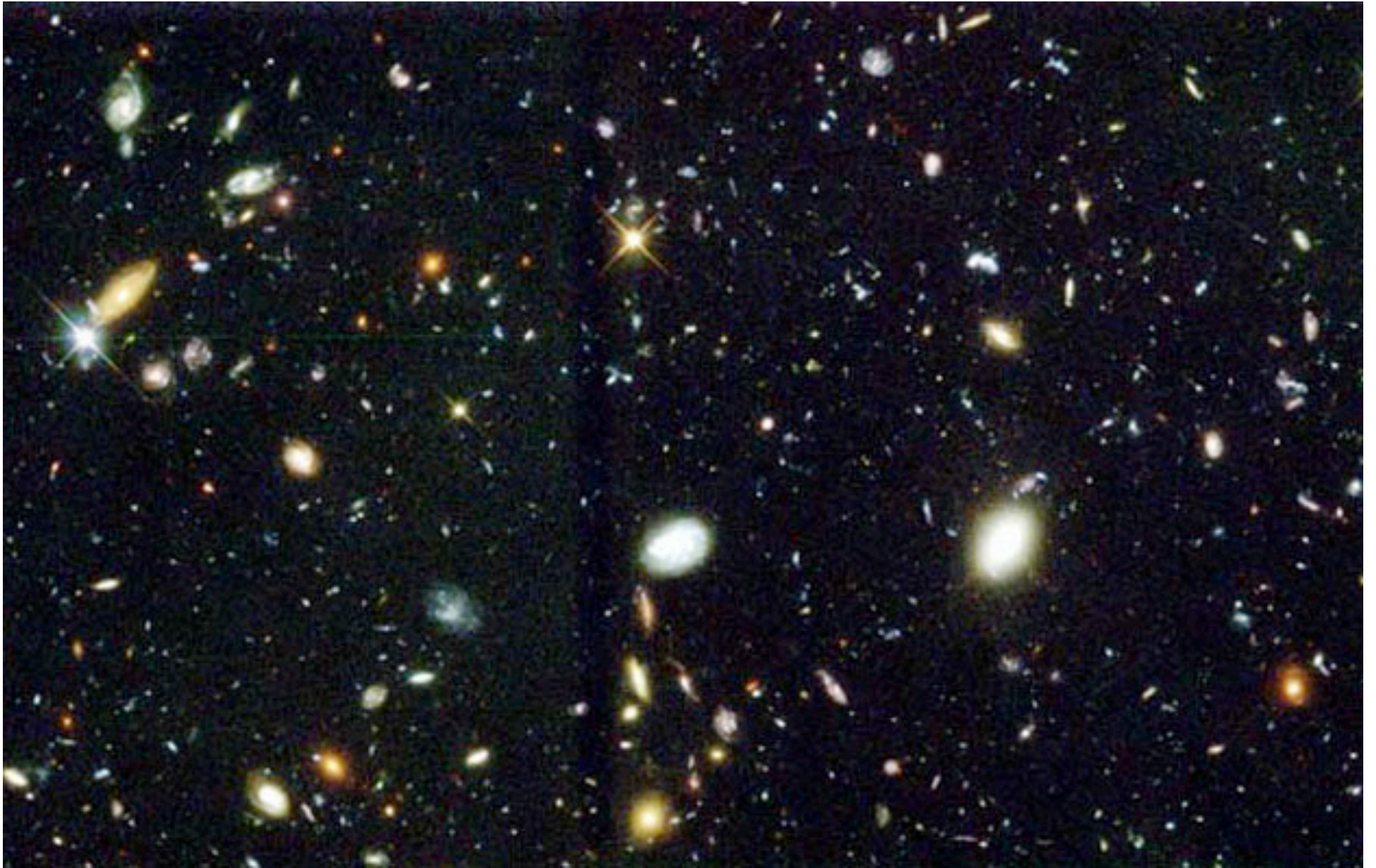
- Homework (about 10 problem sets)
- One Midterm (in class)
- One Short Report on a Journal Article or Topic (maybe)
- One Final Examination (in class or take home?)

Old view:

The Goal of "Particle Physics" is to understand the nature of matter and its interactions at the most fundamental level.

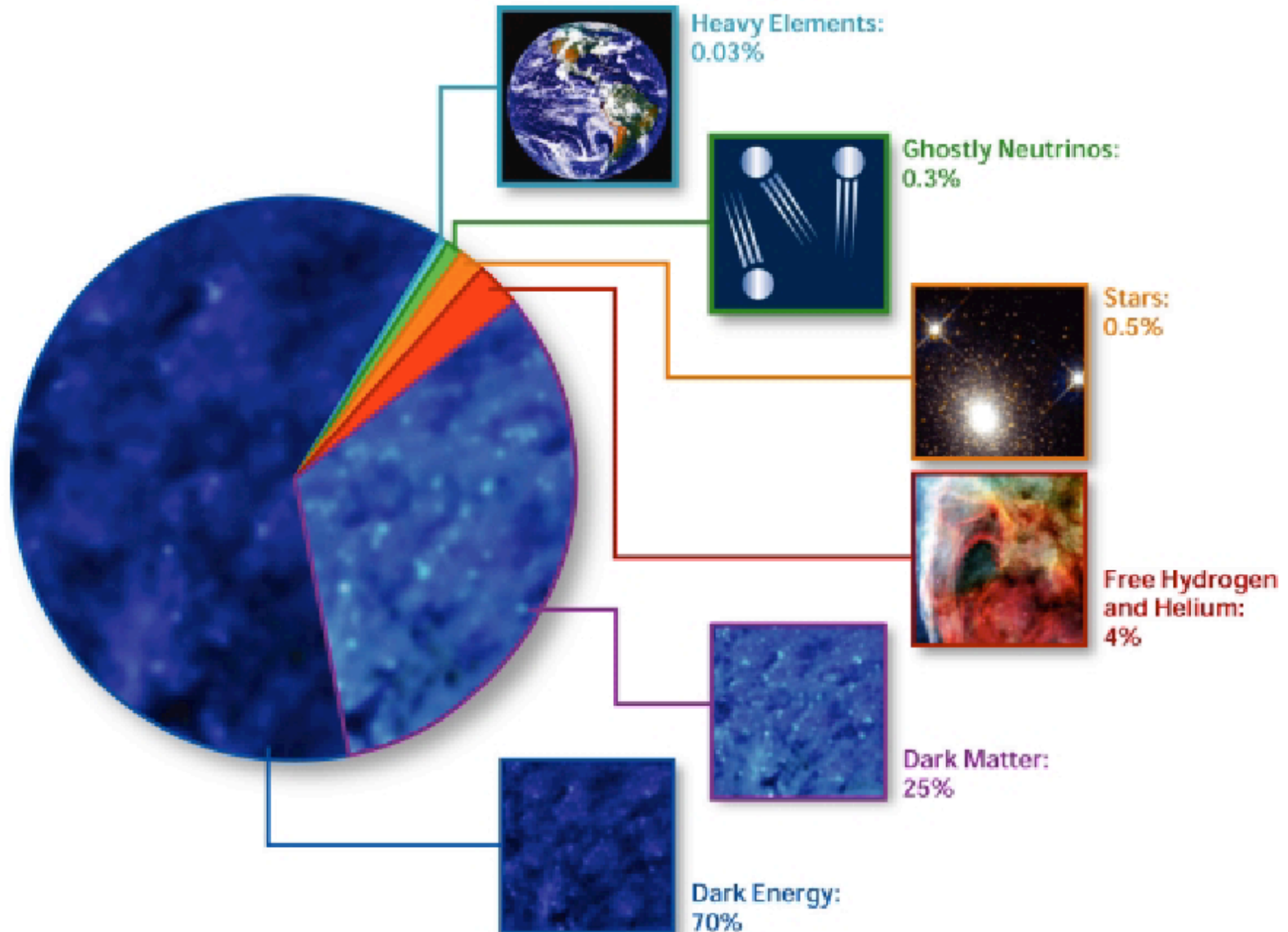
BUT:

It is now realized that to reach the goals of particle physics it is necessary to consider the connection with the very large. Cosmology, Particle Astrophysics.



Hubble Deep Field

What's the Matter



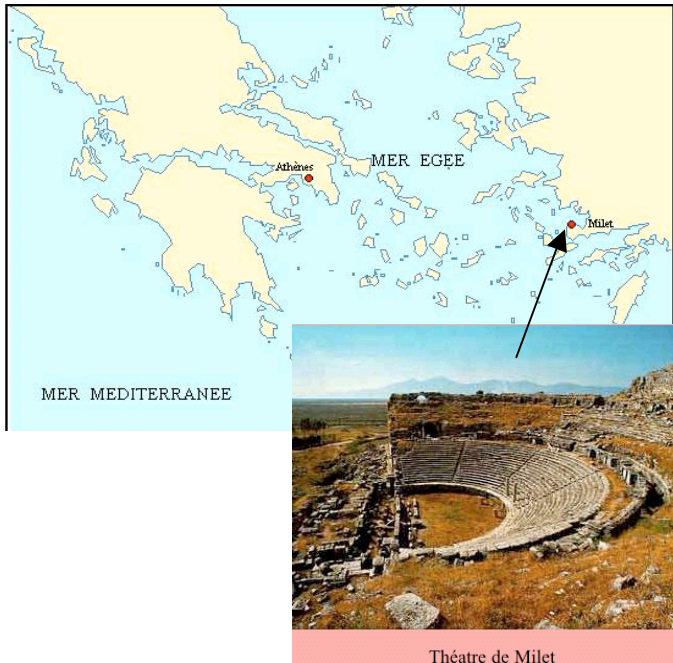
Anaximene of Miletus
600 BCE
Ionic School

Water

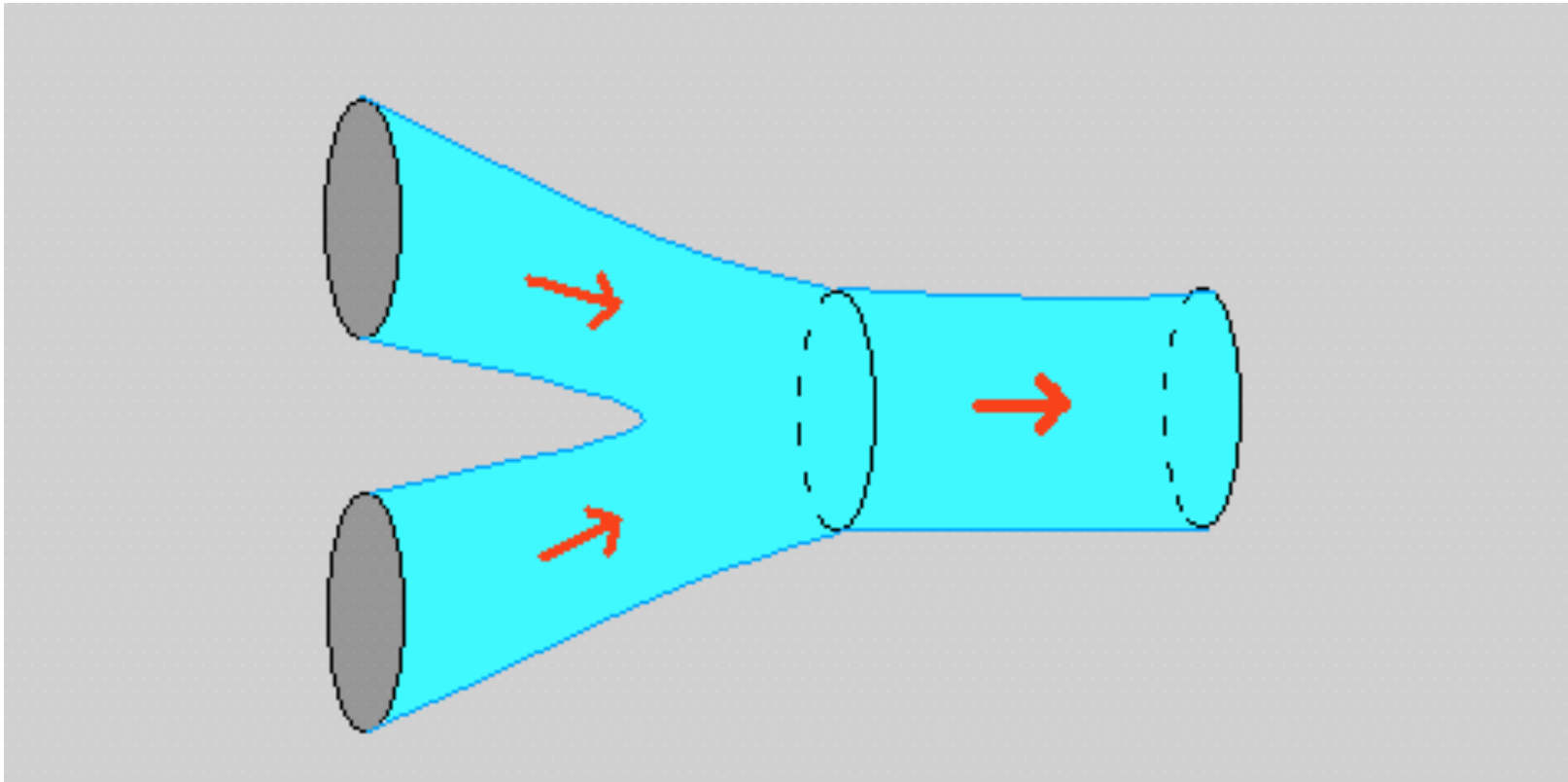
Fire

Air

Earth

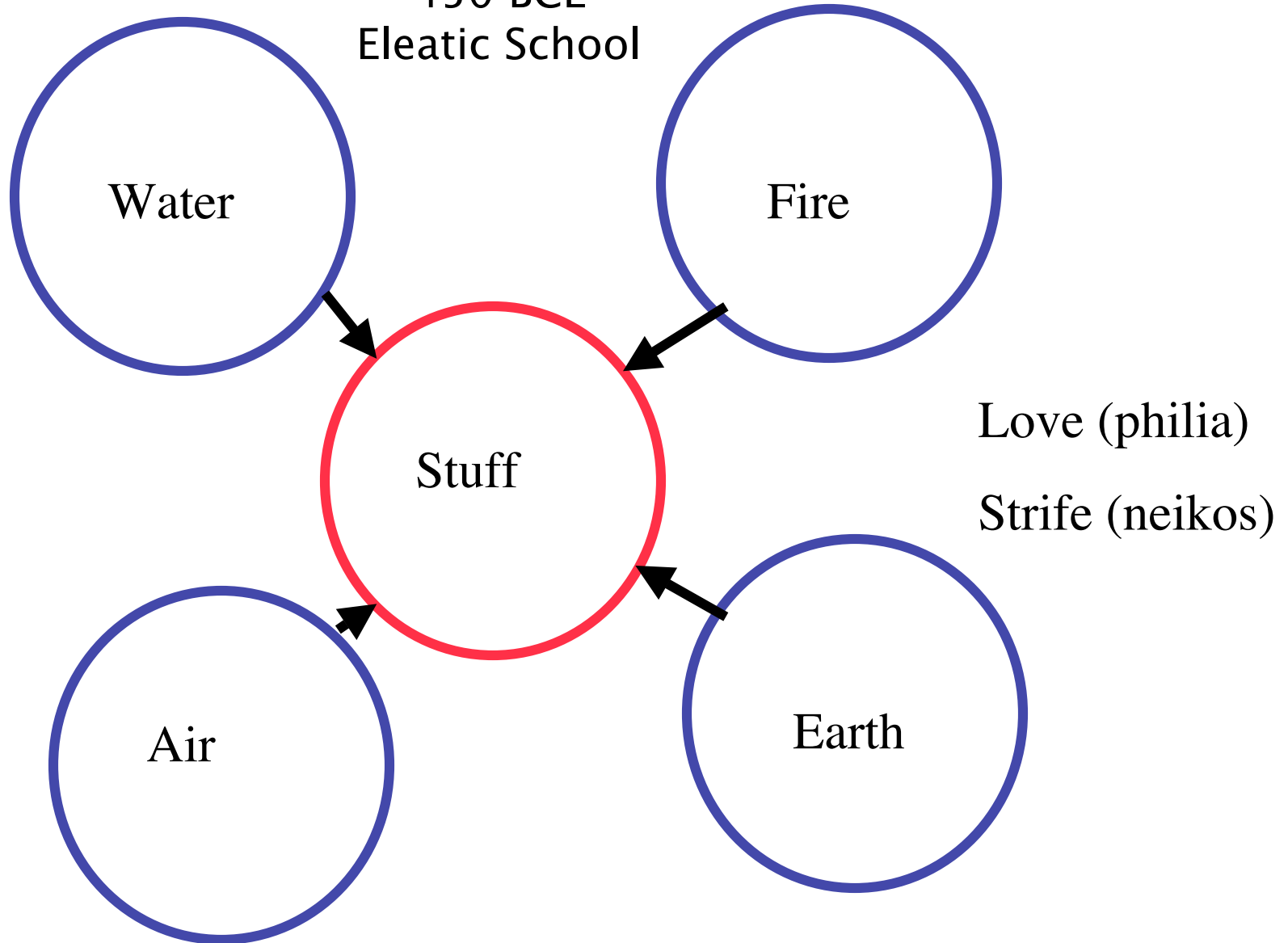


Thales

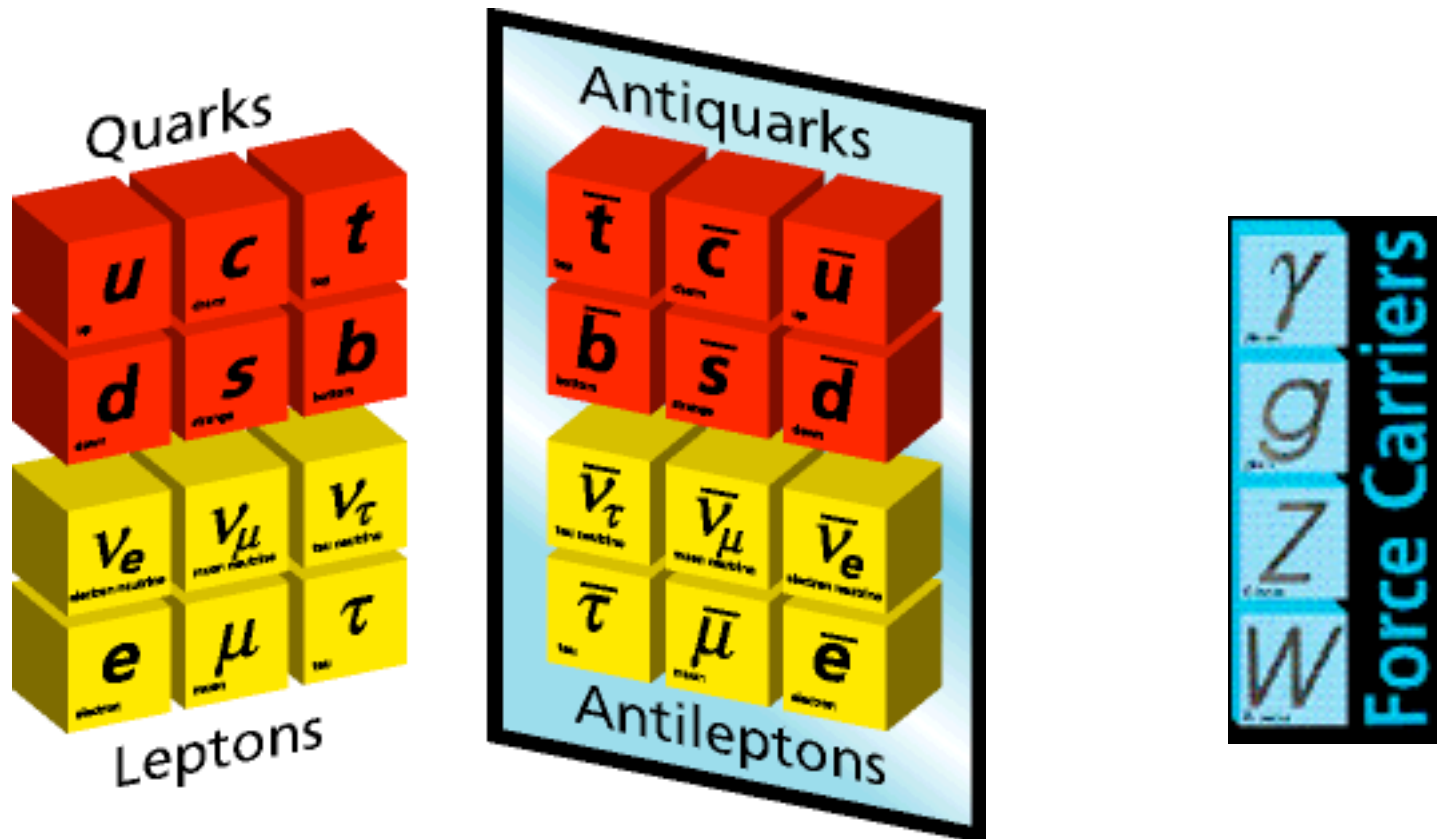


String Theory

Empedocles of Acragas Sicily
450 BCE
Eleatic School



The "Standard Model"

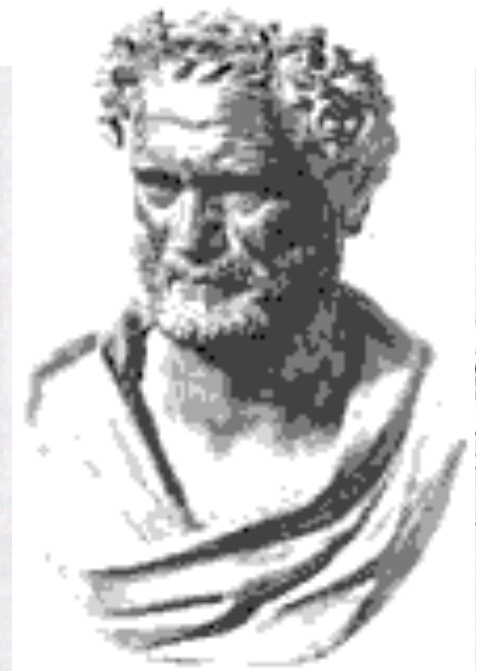


The word "atom" comes from the greek "a-tomos" and signifies "**indivisible**". This notion was invented by **Leucippe of Milet** in 420 before J.C.



His disciple, **Democrite of Abdere** (around 460-370 BC.), explained that matter was made up of particles in perpetual motion and endowed with ideal qualities:

- invisible because of their extremely small size
- indivisible as their name indicates
- solid (no void inside)
- eternal because they are perfect
- surrounded by an empty space (to explain their movement and changes in density)
- having an infinite number of shapes (to explain the diversity observed in nature)

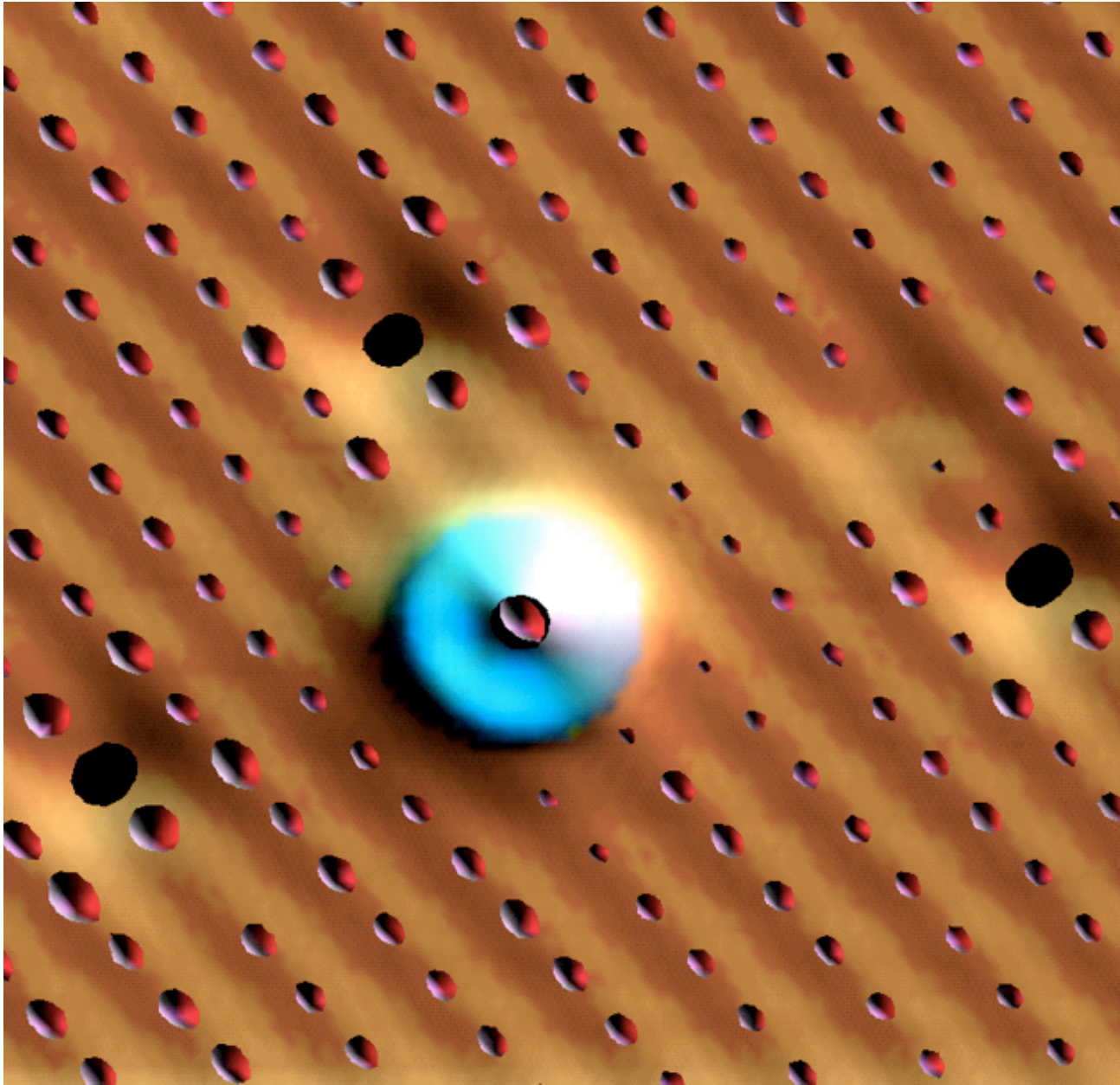


The periodic table of the elements

	1A	2A	3A	4A	5A	6A	7A	8	1B	2B	3B	4B	5B	6B	7B	0		
1	¹ H															² He		
2	³ Li	⁴ Be									⁵ B	⁶ C	⁷ N	⁸ O	⁹ F	¹⁰ Ne		
3	¹¹ Na	¹² Mg									¹³ Al	¹⁴ Si	¹⁵ P	¹⁶ S	¹⁷ Cl	¹⁸ Ar		
4	¹⁹ K	²⁰ Ca	²¹ Sc	²² Ti	²³ V	²⁴ Cr	²⁵ Mn	²⁶ Fe	²⁷ Co	²⁸ Ni	²⁹ Cu	³⁰ Zn	³¹ Ga	³² Ge	³³ As	³⁴ Se	³⁵ Br	³⁶ Kr
5	³⁷ Rb	³⁸ Sr	³⁹ Y	⁴⁰ Zr	⁴¹ Nb	⁴² Mo	⁴³ Tc	⁴⁴ Ru	⁴⁵ Rh	⁴⁶ Pd	⁴⁷ Ag	⁴⁸ Cd	⁴⁹ In	⁵⁰ Sn	⁵¹ Sb	⁵² Te	⁵³ I	⁵⁴ Xe
6	⁵⁵ Cs	⁵⁶ Ba	^L	⁷² Hf	⁷³ Ta	⁷⁴ W	⁷⁵ Re	⁷⁶ Os	⁷⁷ Ir	⁷⁸ Pt	⁷⁹ Au	⁸⁰ Hg	⁸¹ Tl	⁸² Pb	⁸³ Bi	⁸⁴ Po	⁸⁵ At	⁸⁶ Rn
7	⁸⁷ Fr	⁸⁸ Ra	^A															
	^L	⁵⁷ La	⁵⁸ Ce	⁵⁹ Pr	⁶⁰ Nd	⁶¹ Pm	⁶² Sm	⁶³ Eu	⁶⁴ Gd	⁶⁵ Tb	⁶⁶ Dy	⁶⁷ Ho	⁶⁸ Er	⁶⁹ Tm	⁷⁰ Yb	⁷¹ Lu		
	^A	⁸⁹ Ac	⁹⁰ Th	⁹¹ Pa	⁹² U	⁹³ Np	⁹⁴ Pu	⁹⁵ Am	⁹⁶ Cm	⁹⁷ Bk	⁹⁸ Cf	⁹⁹ Es	¹⁰⁰ Fm	¹⁰¹ Md	¹⁰² No	¹⁰³ Lr		

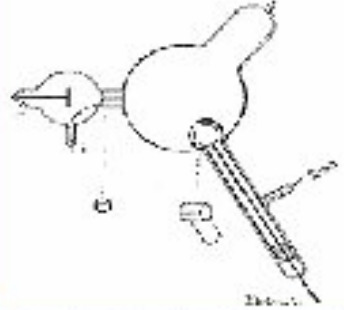
- Metals
- Metalloids
- Non-metals
- Transition Metals
- Gases

Z	Element	Ground-state configuration	Ground level	Ionization energy (eV)
1 H	Hydrogen	1s	$2S_{1/2}$	13.5984
2 He	Helium	1s ²	$1S_0$	24.5874
3 Li	Lithium	1s ² 2s	$2S_{1/2}$	5.3917
4 Be	Beryllium	1s ² 2s ²	$1S_0$	9.3227
5 B	Boron	1s ² 2s ² 2p ¹	$2P_{1/2}$	8.0060
6 C	Carbon	1s ² 2s ² 2p ²	$3P_{0,1,2}$	11.4180
7 N	Nitrogen	1s ² 2s ² 2p ³	$4S_{3/2}$	14.5205
8 O	Oxygen	1s ² 2s ² 2p ⁴	$3P_{2,1,0}$	13.6181
9 F	Fluorine	1s ² 2s ² 2p ⁵	$2P_{3/2,1/2}$	17.4228
10 Ne	Neon	1s ² 2s ² 2p ⁶	$1S_0$	21.5646
11 Na	Sodium	1s ² 2s ² 2p ⁶ 3s ¹	$3S_{1/2}$	5.1391
12 Mg	Magnesium	1s ² 2s ² 2p ⁶ 3s ²	$3S_0$	7.3772
13 Al	Aluminum	1s ² 2s ² 2p ⁶ 3s ² 3p ¹	$3P_{2,1,0}$	6.5809
14 Si	Silicon	1s ² 2s ² 2p ⁶ 3s ² 3p ²	$3P_{2,1,0}$	8.1518
15 P	Phosphorus	1s ² 2s ² 2p ⁶ 3s ² 3p ³	$4S_{3/2}$	10.4867
16 S	Sulfur	[Ne] 3s ² 3p ⁴	$3P_{2,1,0}$	10.3600
17 Cl	Chlorine	[Ne] 3s ² 3p ⁵	$2P^o_{3/2,1/2}$	12.9676
18 Ar	Argon	[Ne] 3s ² 3p ⁶	$1S_0$	15.7596
19 K	Potassium	[Ar] 4s	$4S_{1/2}$	4.3407
20 Ca	Calcium	[Ar] 4s ²	$1S_0$	6.1132
21 Sc	Scandium	[Ar] 3d ¹ 4s ²	$3D_{3/2,5/2}$	6.5615
22 Ti	Titanium	[Ar] 3d ² 4s ²	$3D_{3,1,2}$	6.5816
23 V	Vanadium	[Ar] 3d ³ 4s ²	$3F_{4,3,2}$	6.7447
24 Cr	Chromium	[Ar] 3d ⁵ 4s ¹	$7S_{3/2}$	7.7618
25 Mn	Manganese	[Ar] 3d ⁵ 4s ²	$6S_{5/2}$	7.4347
26 Fe	Iron	[Ar] 3d ⁶ 4s ²	$5D_{4,3,2,1,0}$	7.6454
27 Co	Cobalt	[Ar] 3d ⁷ 4s ²	$4F_{9/2,7/2,5/2,3/2}$	7.8615
28 Ni	Nickel	[Ar] 3d ⁸ 4s ²	$3F_{4,3,2}$	7.7398
29 Cu	Copper	[Ar] 3d ¹⁰ 4s ¹	$4S_{1/2}$	7.7276
30 Zn	Zinc	[Ar] 3d ¹⁰ 4s ²	$1S_0$	9.3996
31 Ga	Gallium	[Ar] 3d ¹⁰ 4s ² 4p ¹	$4P_{3/2,1/2}$	8.1375
32 Ge	Germanium	[Ar] 3d ¹⁰ 4s ² 4p ²	$3P_{2,1,0}$	7.6213
33 As	Arsenic	[Ar] 3d ¹⁰ 4s ² 4p ³	$4S_{3/2}$	9.7701
34 Se	Selenium	[Ar] 3d ¹⁰ 4s ² 4p ⁴	$3P_{2,1,0}$	9.7501
35 Br	Bromine	[Ar] 3d ¹⁰ 4s ² 4p ⁵	$2P^o_{3/2,1/2}$	11.5142
36 Kr	Krypton	[Ar] 3d ¹⁰ 4s ² 4p ⁶	$1S_0$	14.0008
37 Rb	Rubidium	[Kr] 5s	$5S_{1/2}$	4.1771
38 Sr	Strontium	[Kr] 5s ²	$5S_0$	5.6949
39 Y	Yttrium	[Kr] 4d ¹ 5s ²	$5D_{3/2,5/2}$	6.3000
40 Zr	Zirconium	[Kr] 4d ² 5s ²	$5D_{3,1,2}$	6.6339
41 Nb	Niobium	[Kr] 4d ⁴ 5s ¹	$4F_{9/2,7/2,5/2,3/2}$	6.7541
42 Mo	Molybdenum	[Kr] 4d ⁵ 5s ¹	$6S_{5/2}$	7.0915
43 Tc	Technetium	[Kr] 4d ⁵ 5s ²	$6S_{5/2}$	7.2809
44 Ru	Ruthenium	[Kr] 4d ⁷ 5s ¹	$4F_{9/2,7/2,5/2,3/2}$	7.4617
45 Rh	Rhodium	[Kr] 4d ⁸ 5s ¹	$4F_{9/2,7/2,5/2,3/2}$	7.7643
46 Pd	Palladium	[Kr] 4d ¹⁰	$1S_0$	8.3360
47 Ag	Silver	[Kr] 4d ¹⁰ 5s ¹	$5S_{1/2}$	7.5754
48 Cd	Cadmium	[Kr] 4d ¹⁰ 5s ²	$1S_0$	9.0864
49 In	Indium	[Kr] 4d ¹⁰ 5s ² 5p ¹	$5P_{3/2,1/2}$	7.4547
50 Sn	Tin	[Kr] 4d ¹⁰ 5s ² 5p ²	$3P_{2,1,0}$	7.8449
51 Sb	Antimony	[Kr] 4d ¹⁰ 5s ² 5p ³	$4S_{3/2}$	10.4924
52 Te	Tellurium	[Kr] 4d ¹⁰ 5s ² 5p ⁴	$3P_{2,1,0}$	9.4601
53 I	Iodine	[Kr] 4d ¹⁰ 5s ² 5p ⁵	$2P^o_{3/2,1/2}$	10.4536
54 Xe	Xenon	[Kr] 4d ¹⁰ 5s ² 5p ⁶	$1S_0$	12.1298
55 Cs	Cesium	[Xe] 6s	$6S_{1/2}$	3.8912
56 Ba	Barium	[Xe] 6s ²	$6S_0$	5.2121
57 La	Lanthanum	[Xe] 5d ¹ 6s ²	$6D_{3/2,5/2}$	5.5706
58 Ce	Cerium	[Xe] 5d ² 6s ²	$6D_{3,1,2}$	5.5126
59 Pr	Praseodymium	[Xe] 5d ³ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.4790
60 Nd	Neodymium	[Xe] 5d ⁴ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.4252
61 Pm	Promethium	[Xe] 5d ⁵ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.4789
62 Sm	Samarium	[Xe] 5d ⁶ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.6414
63 Eu	Eurium	[Xe] 5d ⁷ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.6763
64 Gd	Gadolinium	[Xe] 5d ⁸ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.9053
65 Tb	Terbium	[Xe] 5d ⁹ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.8291
66 Dy	Dysprosium	[Xe] 5d ¹⁰ 6s ²	$6F_{9/2,7/2,5/2,3/2}$	5.7313
67 Ho	Holmium	[Xe] 5d ¹⁰ 6s ² 6p ¹	$6P_{3/2,1/2}$	6.5323
68 Er	Erbium	[Xe] 5d ¹⁰ 6s ² 6p ²	$3P_{2,1,0}$	6.4798
69 Tm	Thulium	[Xe] 5d ¹⁰ 6s ² 6p ³	$4S_{3/2}$	6.1804
70 Yb	Ytterbium	[Xe] 5d ¹⁰ 6s ² 6p ⁴	$3P_{2,1,0}$	6.2541
71 Lu	Lutetium	[Xe] 5d ¹⁰ 6s ² 6p ⁵	$2P^o_{3/2,1/2}$	6.6254
72 Hf	Hafnium	[Xe] 5d ² 6s ²	$5D_{3,1,2}$	6.8271
73 Ta	Tantalum	[Xe] 5d ³ 6s ²	$5D_{3,1,2}$	6.8814
74 W	Tungsten	[Xe] 5d ⁴ 6s ²	$5D_{3,1,2}$	7.0813
75 Re	Rhenium	[Xe] 5d ⁵ 6s ²	$5D_{3,1,2}$	7.4344
76 Os	Osmium	[Xe] 5d ⁶ 6s ²	$5D_{3,1,2}$	7.7691
77 Ir	Iridium	[Xe] 5d ⁷ 6s ²	$5D_{3,1,2}$	8.1024
78 Pt	Platinum	[Xe] 5d ⁹ 6s ¹	$5D_{3,1,2}$	8.4818
79 Au	Gold	[Xe] 5d ¹⁰ 6s ¹	$6S_{1/2}$	8.8113
80 Hg	Mercury	[Xe] 5d ¹⁰ 6s ²	$1S_0$	10.3744
81 Tl	Thallium	[Xe] 5d ¹⁰ 6s ² 6p ¹	$6P_{3/2,1/2}$	8.3146
82 Pb	Lead	[Xe] 5d ¹⁰ 6s ² 6p ²	$3P_{2,1,0}$	8.4173
83 Bi	Bismuth	[Xe] 5d ¹⁰ 6s ² 6p ³	$4S_{3/2}$	10.0127
84 Po	Polonium	[Xe] 5d ¹⁰ 6s ² 6p ⁴	$3P_{2,1,0}$	8.4143
85 At	Astatine	[Xe] 5d ¹⁰ 6s ² 6p ⁵	$2P^o_{3/2,1/2}$	9.1264
86 Rn	Radon	[Xe] 5d ¹⁰ 6s ² 6p ⁶	$1S_0$	10.9726
87 Fr	Francium	[Rn] 7s	$7S_{1/2}$	4.0792
88 Ra	Radium	[Rn] 7s ²	$7S_0$	5.7985
89 Ac	Actinium	[Rn] 6d ¹ 7s ²	$7D_{3/2,5/2}$	5.1091
90 Th	Thorium	[Rn] 6d ² 7s ²	$7D_{3,1,2}$	5.3344
91 Pa	Protactinium	[Rn] 6d ³ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	5.3411
92 U	Uranium	[Rn] 6d ⁴ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	5.5937
93 Np	Neptunium	[Rn] 6d ⁵ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	5.7956
94 Pu	Plutonium	[Rn] 6d ⁶ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	5.9344
95 Am	Americium	[Rn] 6d ⁷ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	6.0247
96 Cm	Curium	[Rn] 6d ⁸ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	6.1331
97 Bk	Berkelium	[Rn] 6d ⁹ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	6.2569
98 Cf	Californium	[Rn] 6d ¹⁰ 7s ²	$7F_{9/2,7/2,5/2,3/2}$	6.3654
99 Es	Einsteinium	[Rn] 6d ¹⁰ 7s ² 7p ¹	$7P_{3/2,1/2}$	6.5809
100 Fm	Fermium	[Rn] 6d ¹⁰ 7s ² 7p ²	$3P_{2,1,0}$	6.5008
101 Md	Mendelevium	[Rn] 6d ¹⁰ 7s ² 7p ³	$4S_{3/2}$	6.6902
102 No	Nobelium	[Rn] 6d ¹⁰ 7s ² 7p ⁴	$3P_{2,1,0}$	6.6801
103 Lr	Lawrencium	[Rn] 6d ¹⁰ 7s ² 7p ⁵	$2P^o_{3/2,1/2}$	6.9302

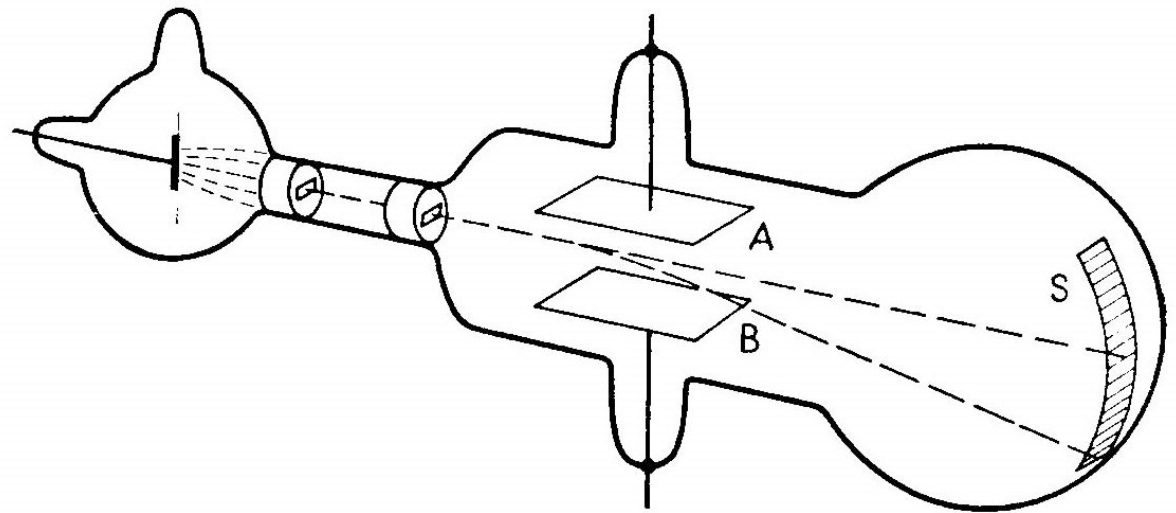


STM image of a Xeon atom sitting on top of a Nickel surface

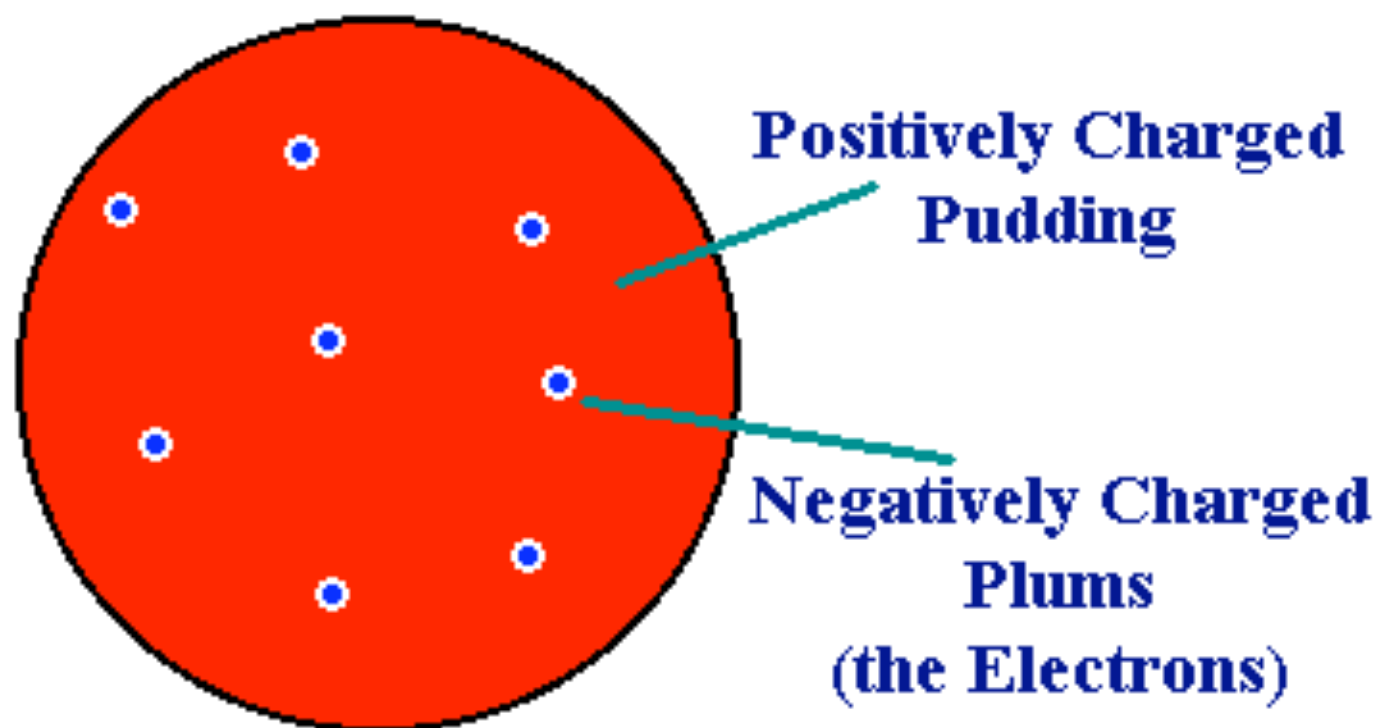
Discovery of the Electron

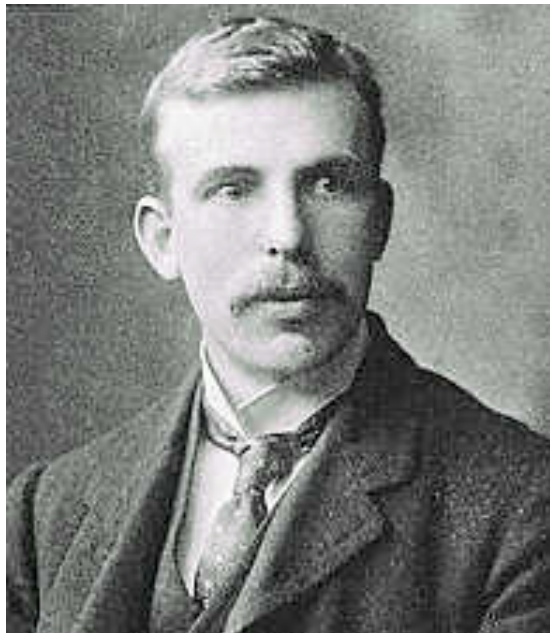


- J. J. Thompson (1856-1940) in 1897 announced discovery that cathode rays:
- 1) Had negative charge
- 2) 2000 less massive than protons.

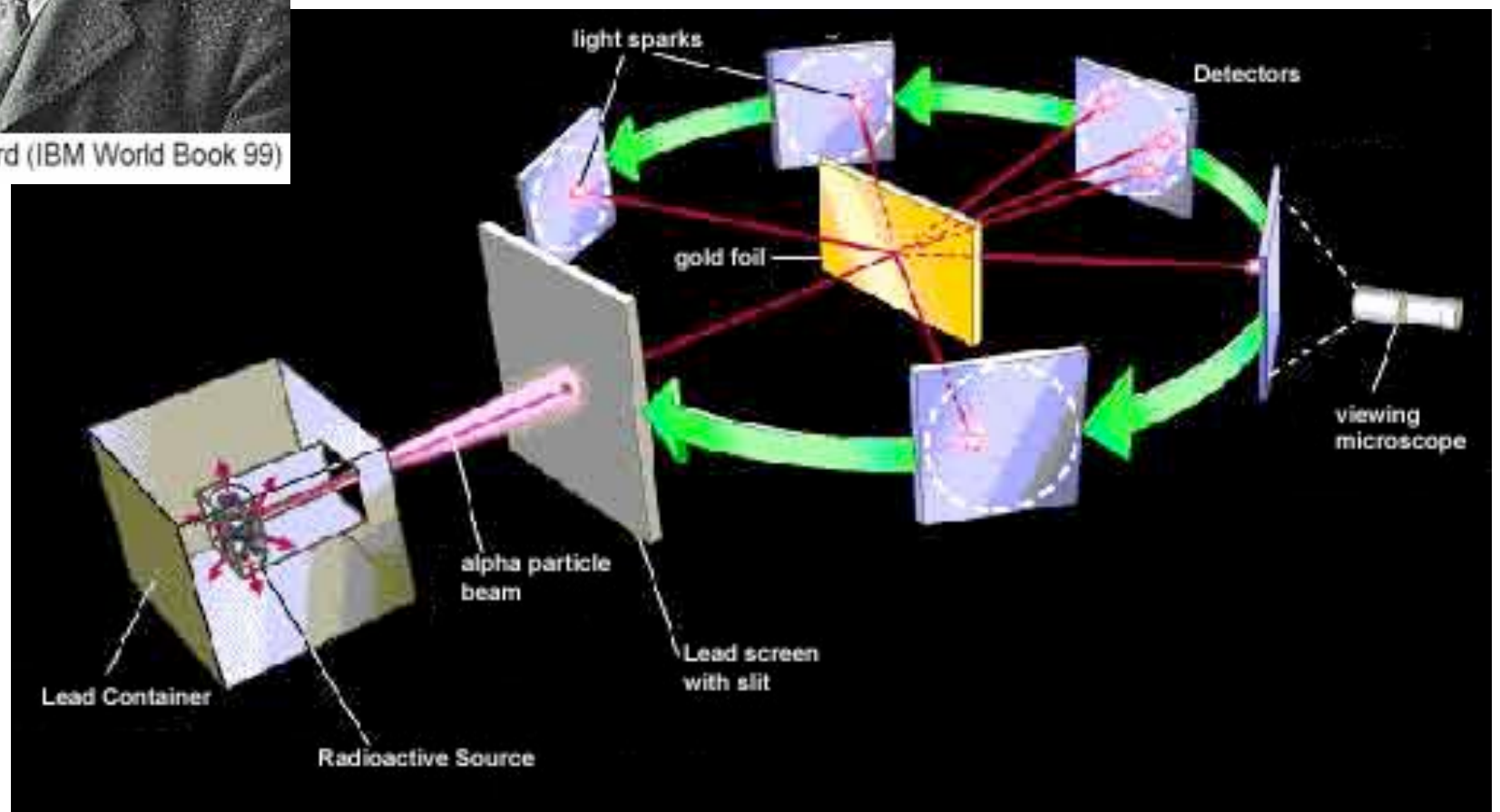


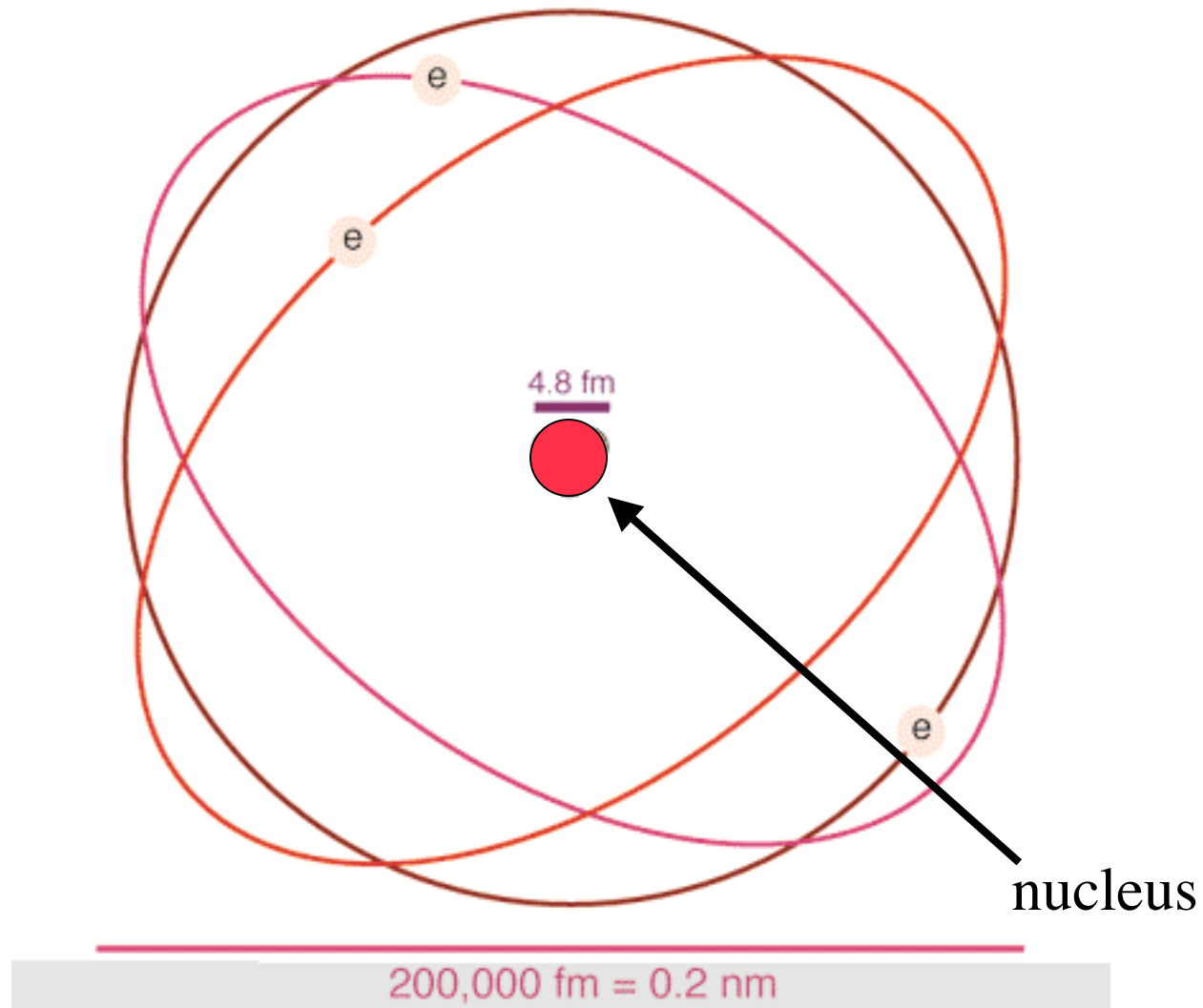
The Plum Pudding Model





Ernest Rutherford (IBM World Book 99)

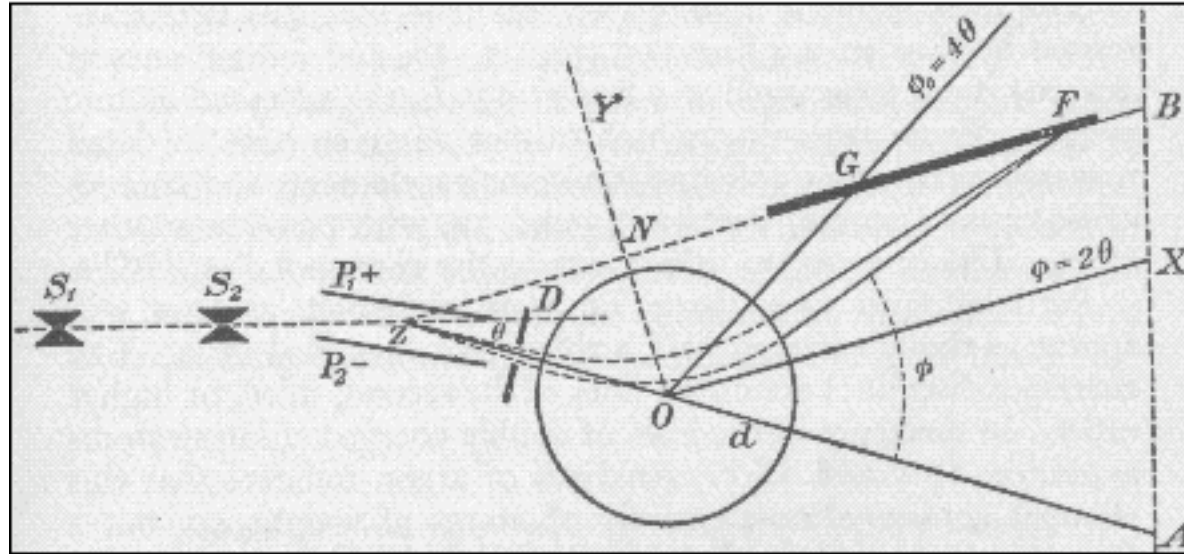




Lithium Atom



Aston's spectrometer



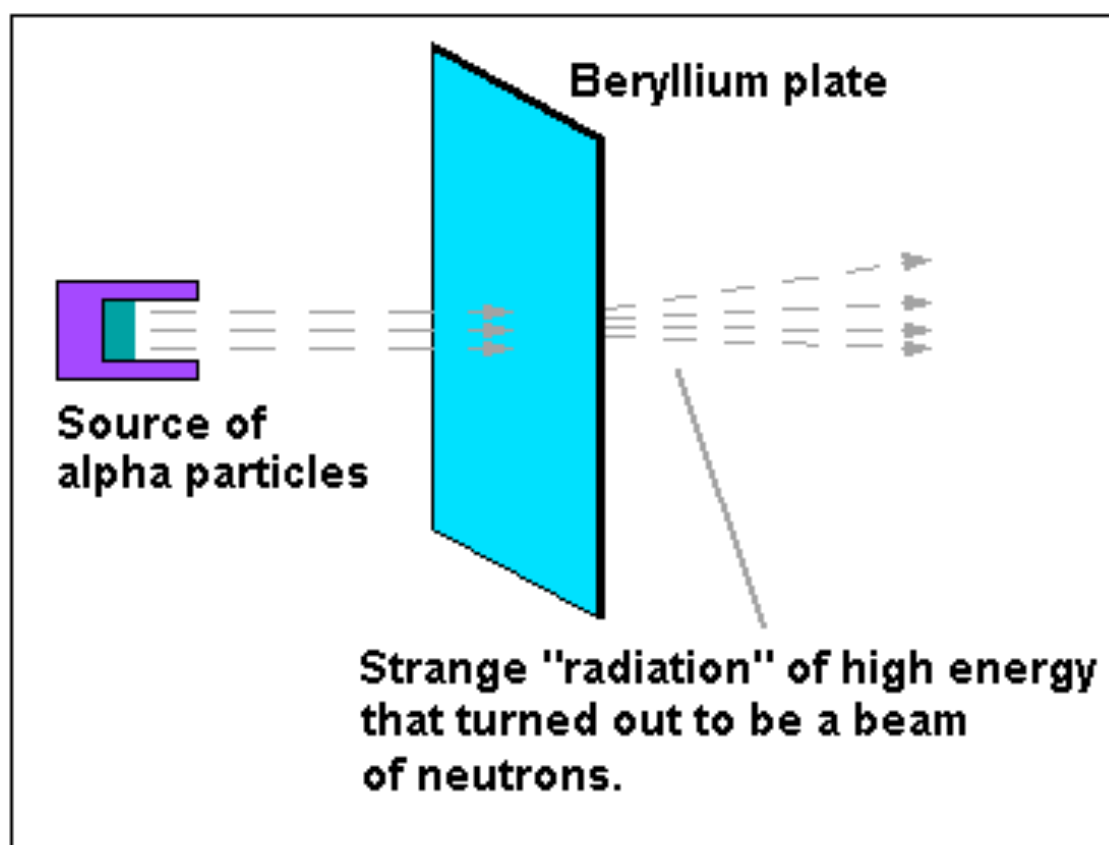
Aston's Mass Spectograph 1919

Whilst working at the Cavendish Laboratory in Cambridge under J J Thomson, Francis William Aston (1877-1945) undertook a series of experiments that led to the discoveries by which he is now best remembered. Aston was assigned to improving Thomson's apparatus in which a beam of positively-charged particles (positive rays) was deflected by a combination of electric and magnetic fields into sharp visible curves, each representing an individual particle's charge-to-mass ratio.

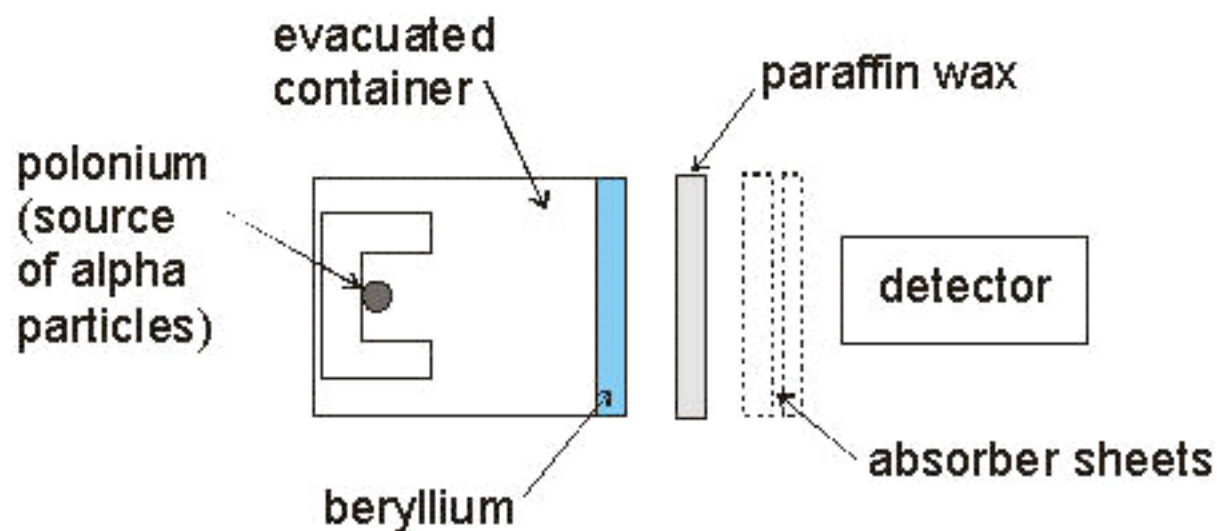
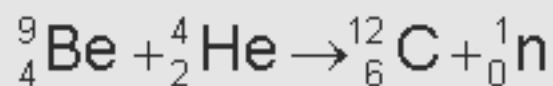
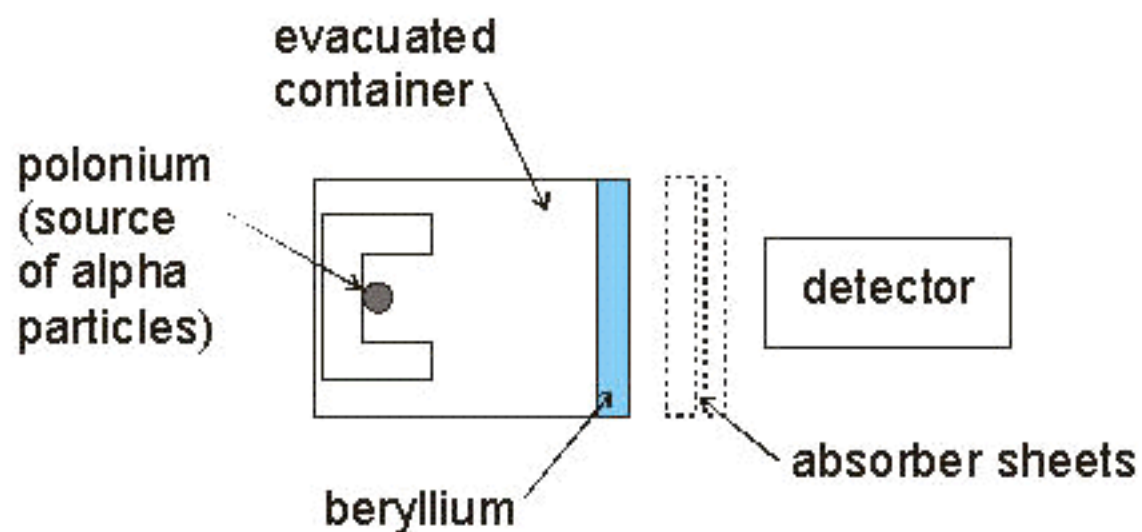
The key advance Aston made to Thomson's apparatus was his arrangement of the electric and magnetic deflecting fields so as to bring rays of uniform charge-to-mass ratio to sharp focus on a photographic plate. Aston devised several methods for calibrating his instrument and, in the case of neon, obtained mass lines on his photographic plate at 20 and 22 with the intensities of the lines showing that the two particles occurred in the ratio of 10:1, consistent with an average mass of 20.20, the known atomic weight of neon.

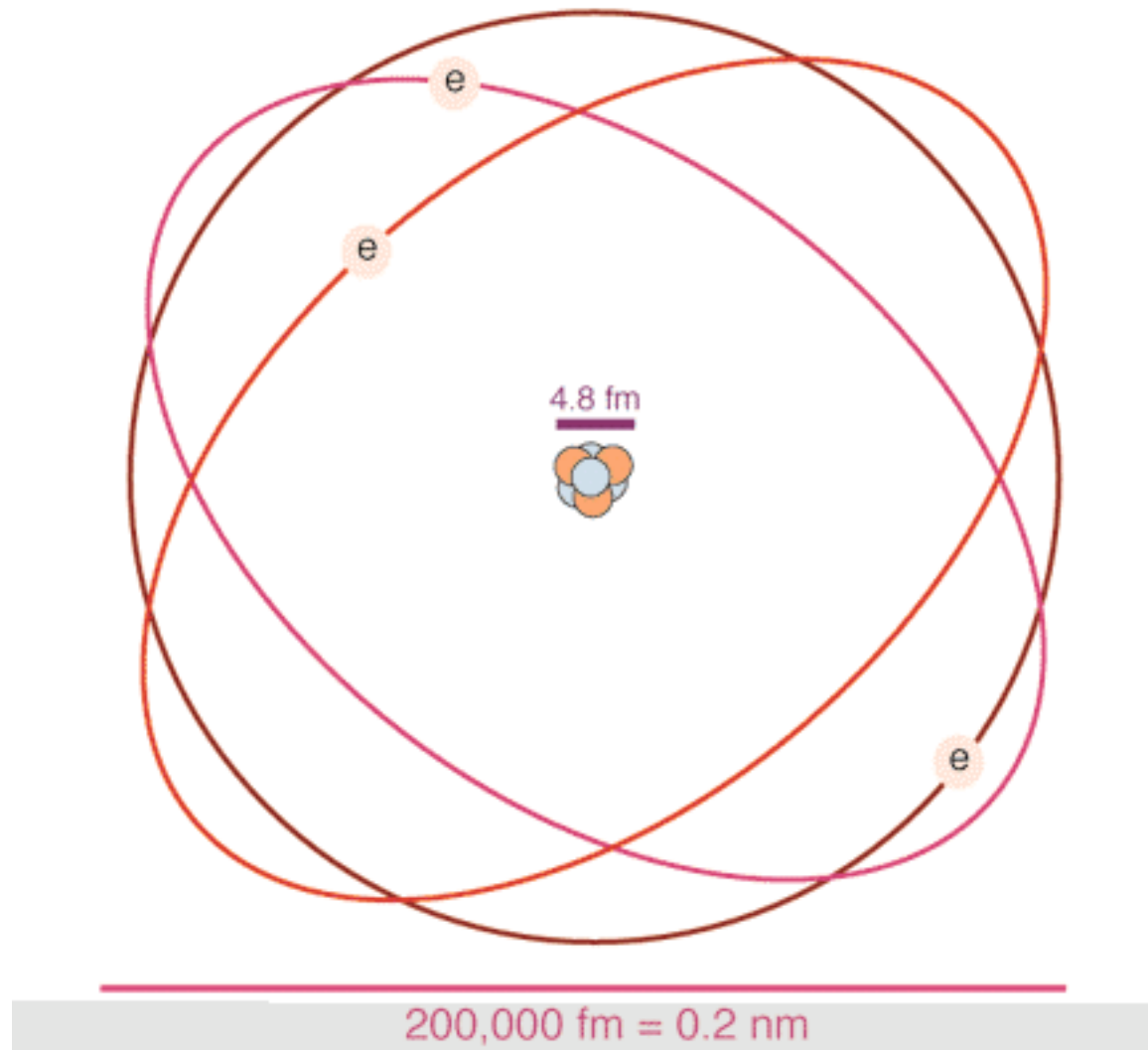
He had earlier shown that both masses were substances with the same properties as neon and thus neon was the first non-radioactive element proven to be isotopic (atoms with the same chemical properties, but different atomic mass).

In the short time before Aston was presented with his Nobel Prize, he had demonstrated the existence of isotopes in some 30 other gaseous elements.

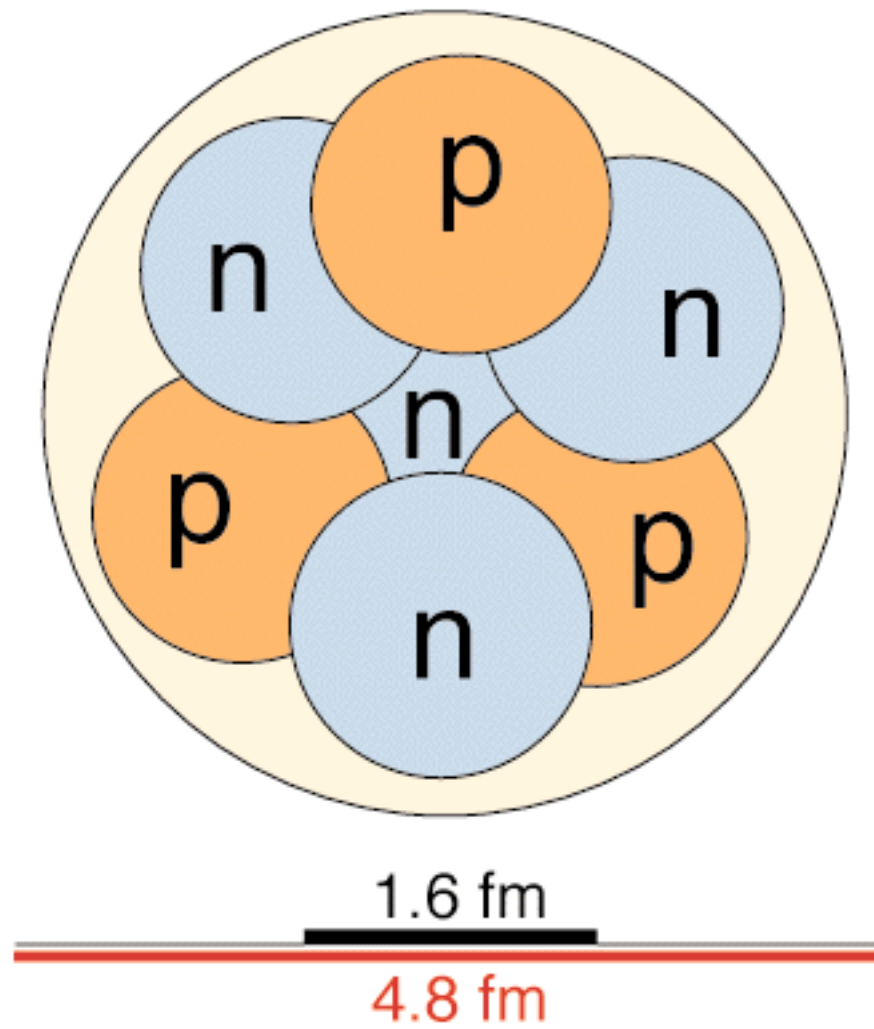


Detection of neutrons

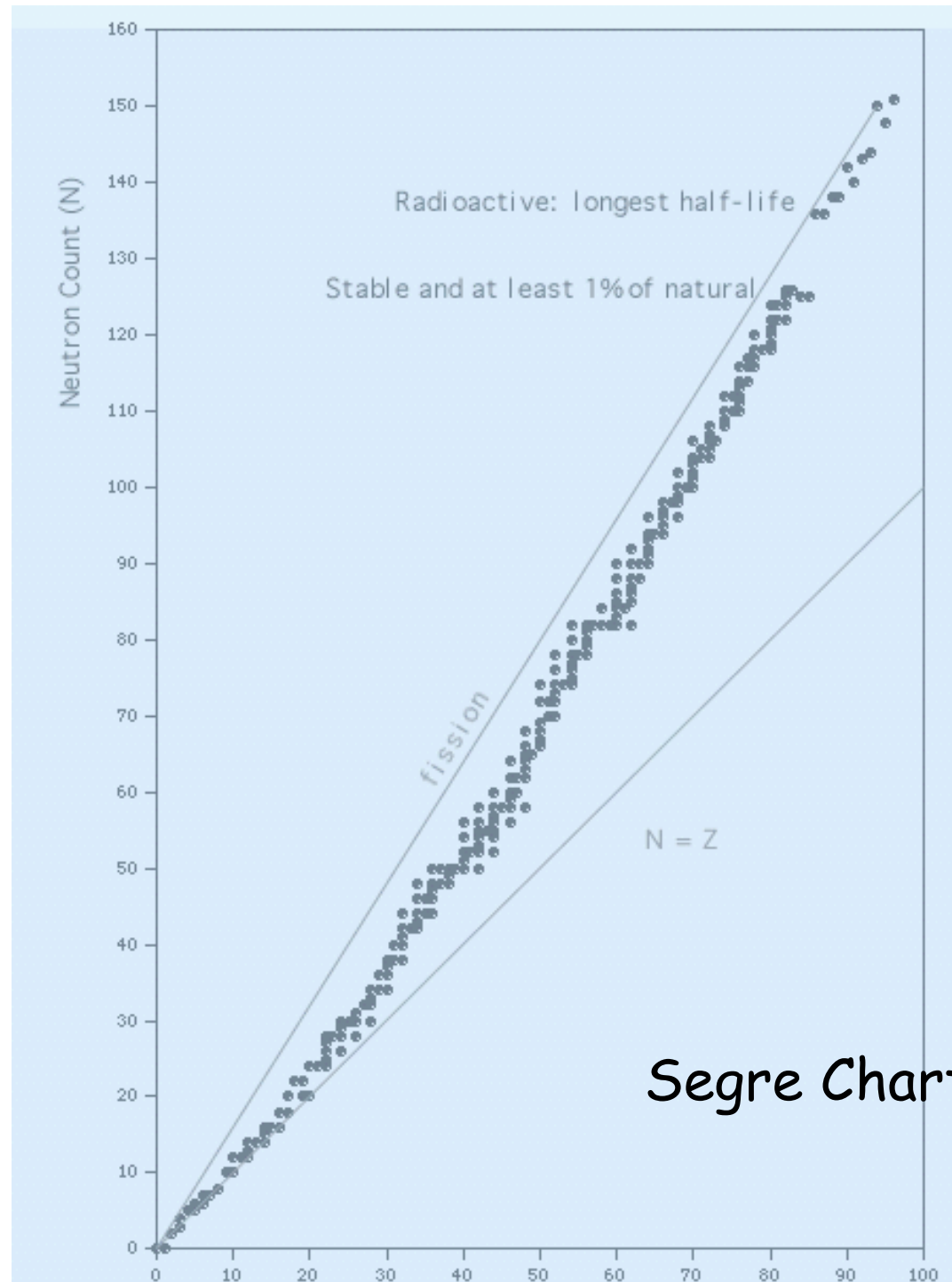




Lithium Atom

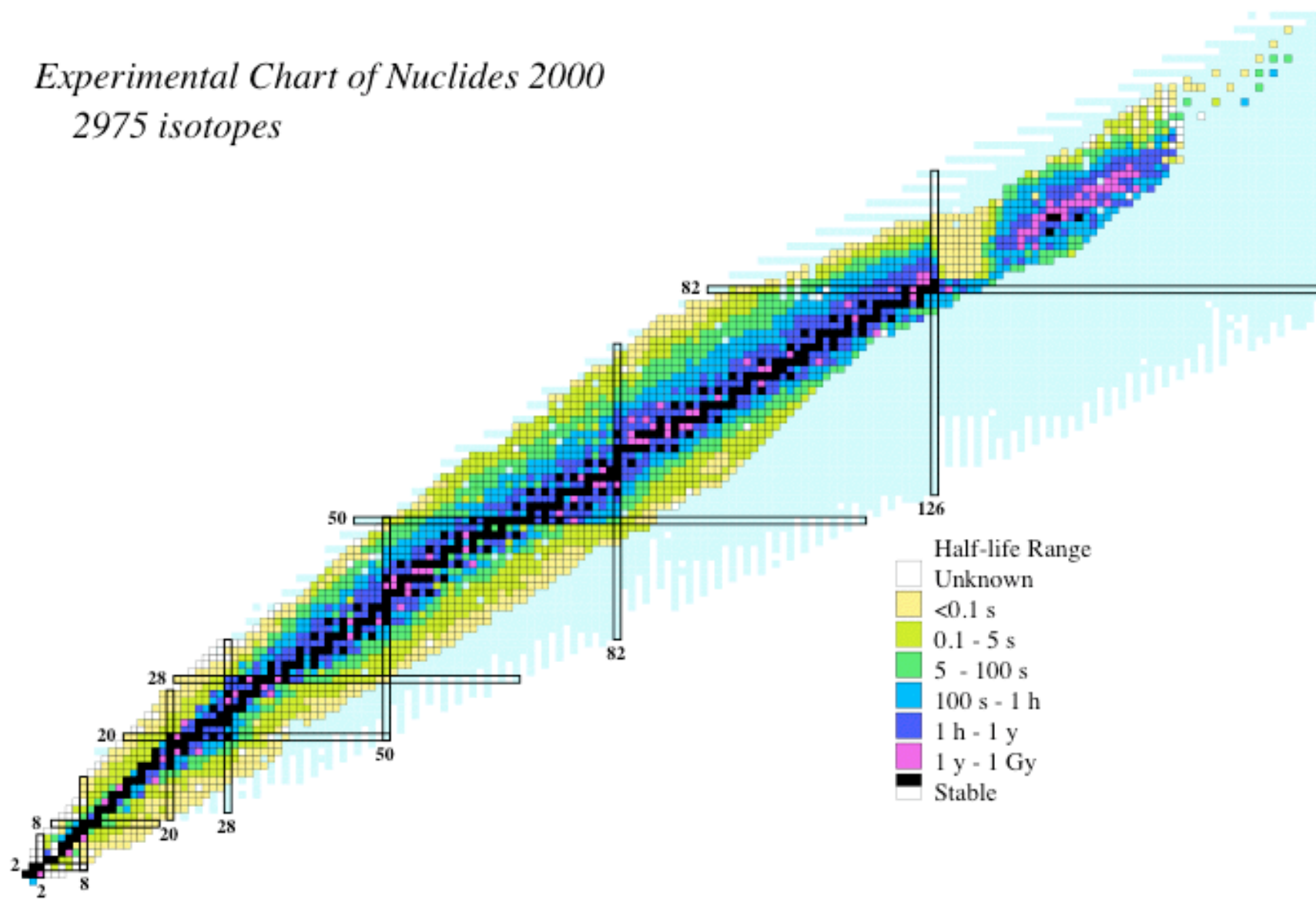


${}^7\text{Li}$ Nucleus



Segre Chart

Experimental Chart of Nuclides 2000
 2975 isotopes



Beta Decay

$$M_{parent}c^2 \Rightarrow E_{daughter} + E_{electron}$$

$$KE_{electron} \approx M_{parent}c^2 - M_{daughter}c^2 - m_{electron}c^2$$

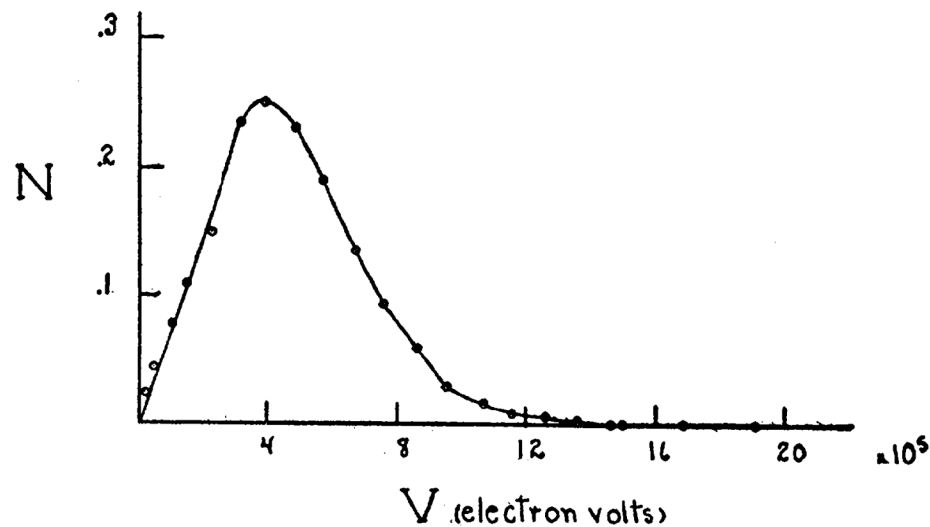
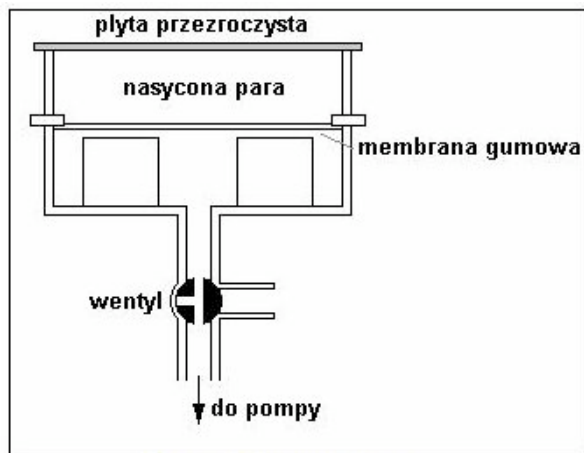


FIG. 5. Energy distribution curve of the beta-rays.

Continuous Beta Spectrum



Schemat komory Wilsona.



Wilson Cloud Chamber

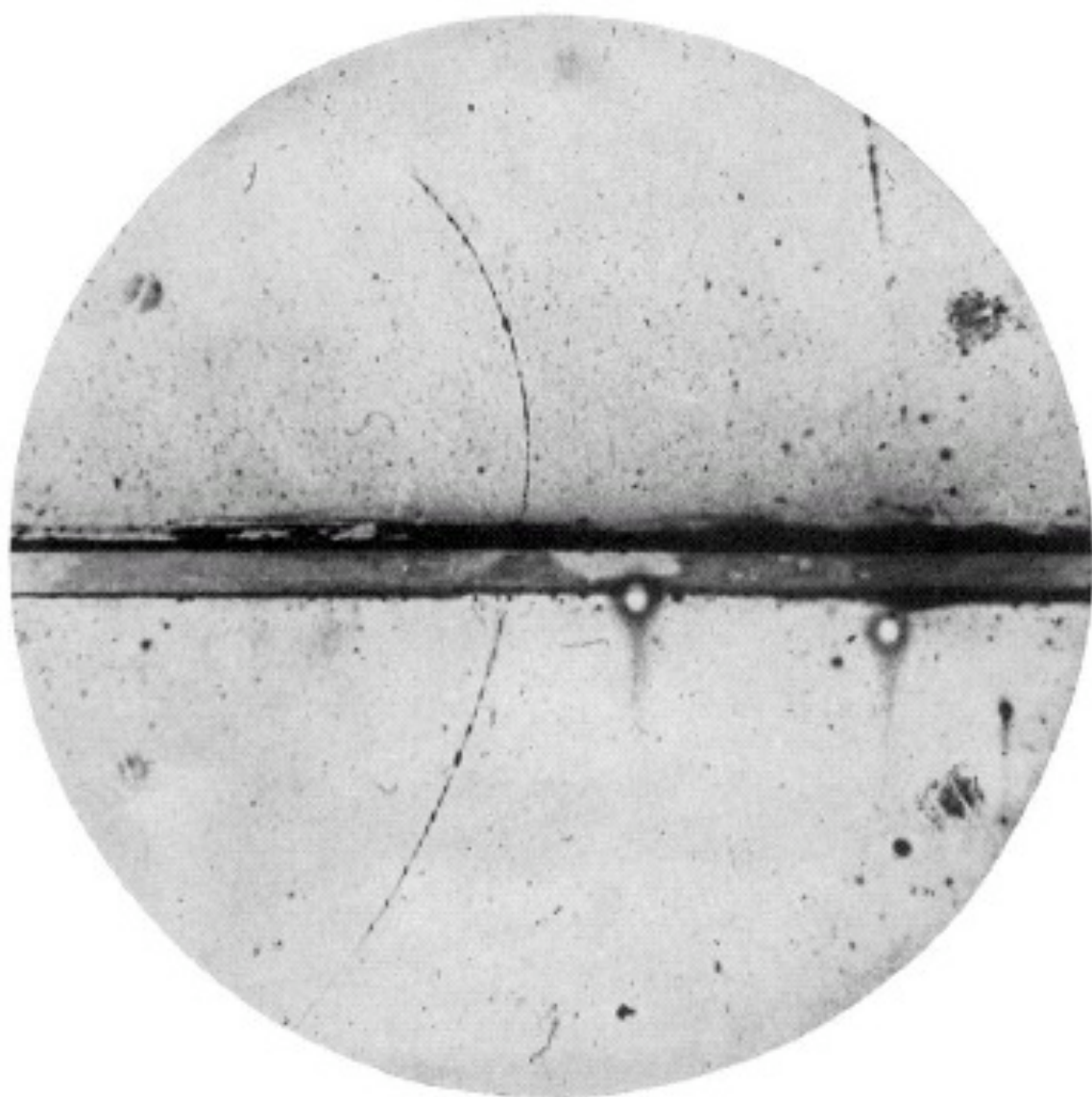
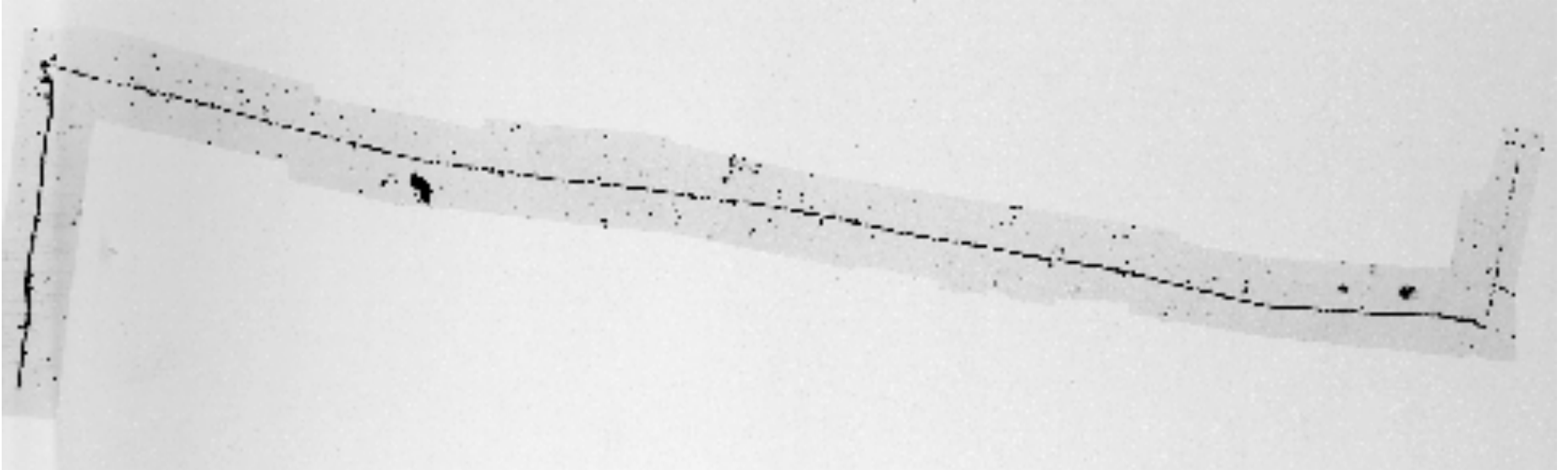
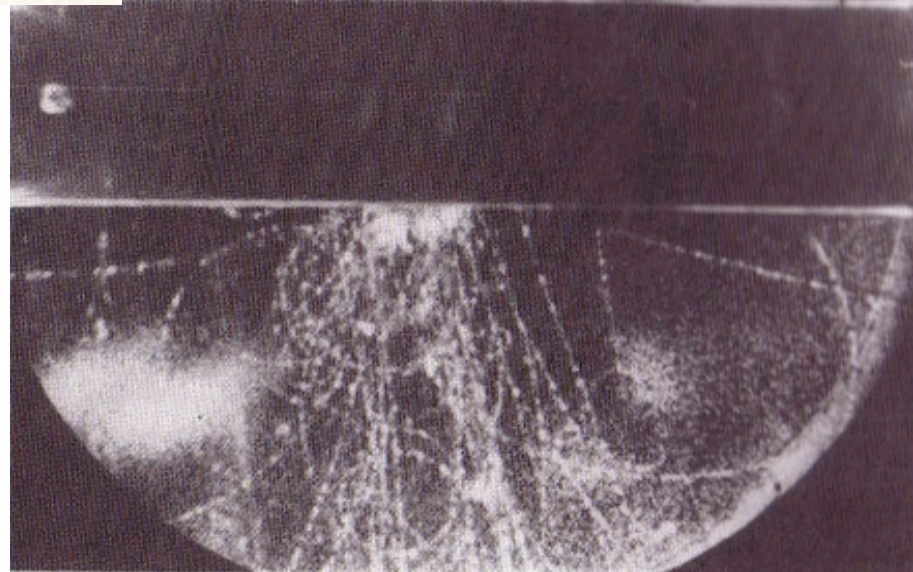
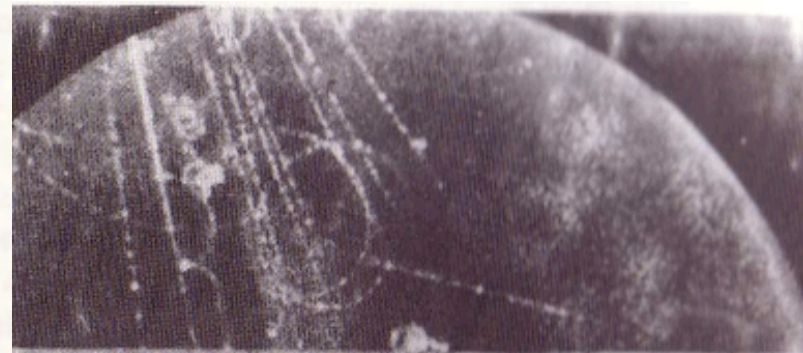
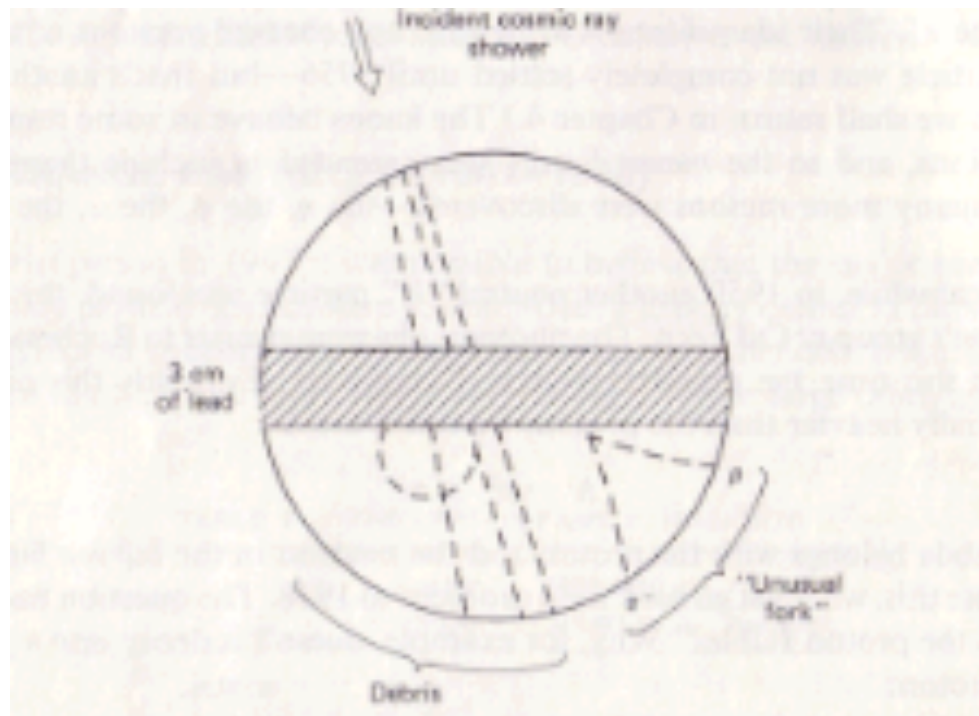


FIG. 1. A 63 million volt positron ($H_p = 2.1 \times 10^5$ gauss-cm) passing through a 6 mm lead plate and emerging as a 23 million volt positron ($H_p = 7.5 \times 10^4$ gauss-cm). The length of this latter path is at least ten times greater than the possible length of a proton path of this curvature.



Discovery of the pion

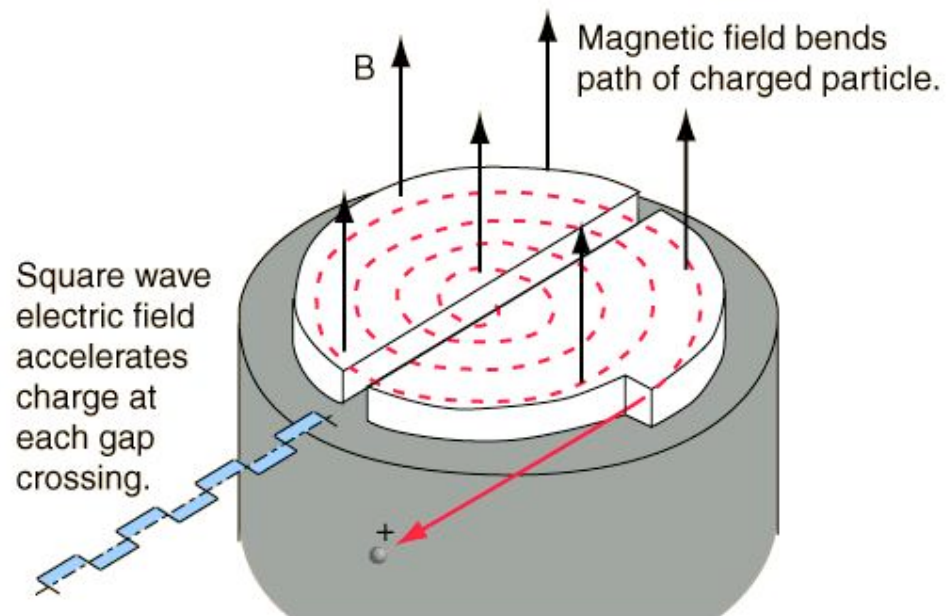
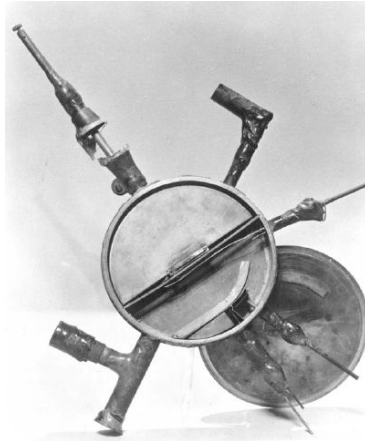




First Strange Particle



Lawrence



The Cyclotron



Segre



Chamberlain



Bevatron

